NPS-GSBPP-05-009

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

Spiral Development: A Perspective

30 June 2005

by

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Graduate School of Business & Public Policy

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Prepared for: Naval Sea Systems Command and
Naval Postgraduate School, Monterey, California 93943

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The Acquisition Chair, Graduate School of Business & Public Policy, Naval Postgraduate School supported the funding of the research presented herein.

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REPORT DOCUMENTATION PAGE

Form approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	**2. REPORT DATE** 30 JUNE 2005	**3. REPORT TYPE AND DATES COVERED** 1 OCTOBER 2004 – 30 JUNE 2005

4. TITLE AND SUBTITLE
Spiral Development: A Perspective

5. FUNDING

6. AUTHOR (S)
Dr. Aruna Apte, Assistant Professor, Graduate School of Business & Public Ploicy

7. PERFORMING ORGANIZATION NAME (S) AND ADDRESS (ES)
NAVAL POSTGRADUATE SCHOOL
GRADUATE SCHOOL OF BUSINESS AND PUBLIC POLICY
555 DYER ROAD
MONTEREY, CA 93943-5103

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-GSBPP-05-009

9. SPONSORING/MONITORING AGENCY NAME (S) AND ADDRESS (ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words.)

Many view the Department of Defense's acquisition process as ripe for repair. Shortcomings of predominantly used acquisition approaches, such as the Block approach or Pre-planned Product Improvement (P3I) to fulfill system requirements, have led to a new approach in Evolutionary Acquisition strategy: a process called spiral development. This research study focuses on the process, promise, and limitations of spiral development. This study is centered on the key issues that distinguish a spiral approach from the traditional approaches implemented by the DoD. This study describes the fundamentals of the process of spiral acquisition: increments, characteristics of the increments, and the capabilities they deliver using a simple model. The interest of this research is in understanding the concept of spiral acquisition as it applies, specifically, to Program Managers. In conclusion, the analysis so far suggests two key issues: the necessity for a template or a set of rules that will aid Program Managers in understanding and implementing the concept of spiral development, and the role of modularity in spiral development. This research plans to address these issues and provide a possible road map towards a solution to them.

14. SUBJECT TERMS
Evolutionary Acquisition, spiral development, Program Managers, process, promise, limitations, modularity

15. NUMBER OF PAGES 31

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT: UNCLASSIFIED	**18. SECURITY CLASSIFICATION OF THIS PAGE:** UNCLASSIFIED	**19. SECURITY CLASSIFICATION OF ABSTRACT:** UNCLASSIFIED	**20. LIMITATION OF ABSTRACT:** UNLIMITED

NSN 7540-01-280-5800
298 (Rev. 2-89)

Standard Form

Prescribed by
ANSI Std 239-18

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Abstract

Many view the Department of Defense's (DoD) acquisition process as ripe for repair. Shortcomings of predominantly used acquisition approaches, such as the Block approach or Pre-planned Product Improvement (P3I) to fulfill system requirements, have led to a new approach in Evolutionary Acquisition strategy: a process called spiral development. This research study focuses on the process, promise, and limitations of spiral development. The study is centered on the key issues that distinguish a spiral approach from the traditional approaches implemented by the DoD. This study describes the fundamentals of the process of spiral development: increments, characteristics of the increments, and the capabilities they deliver using a simple model. The interest of this research is in understanding the concept of spiral development as it applies, specifically, to Program Managers. In conclusion, the analysis so far suggests two key issues: the necessity for a template or a set of rules that will aid Program Managers in understanding and implementing the concept of spiral development, and the role of modularity in spiral development. This research plans to address these issues and provide a possible road map towards a solution to them.

Keywords: Evolutionary Acquisition, spiral development, Program Managers, process, promise, limitations, modularity

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Acknowledgements

I am grateful to RADM Jim Greene and Dr. Keith Snider for providing me with this opportunity to do research in the area of Evolutionary Acquisition and spiral development. Additional thanks go to Karey Shaffer for her constant support through this project.

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Dr. Aruna Apte is an Assistant Professor in the department of Logistics, Graduate School of Business and Public Policy, at the Naval Postgraduate School, Monterey, California. She received her PhD in Operations Research from the School of Engineering at the Southern Methodist University in Dallas, Texas. Her earlier education includes a Master's in Mathematics and credits towards a PhD in Mathematics from Temple University, Philadelphia, Pennsylvania. She has taught in the Cox School of Business, School of Engineering and the Department of Mathematics at Southern Methodist University. She has over twenty years of experience in teaching operations management, operations research, and mathematics courses at the undergraduate and graduate levels in the resident and remote programs.

Apte has successfully completed various research projects involving applications of mathematical models and optimization techniques. Her research interests are in the areas of developing mathematical models and algorithms for complex, real-world operational problems using techniques of combinatorial optimization, network programming, and mixed integer programming based on heuristic search methods. She is interested in developing theoretical concepts in mathematical programming. It is also important to her that her research is directly applicable to practical problems and has significant value-adding potential. Her research articles have been published in prestigious journals including *Naval Research Logistics* and *Interfaces.* She has published one article and two are forthcoming in the *Acquisition Research Sponsored Report Series, GSBPP, NPS*. She also has a patent pending for the "SONET Ring Designer Tool," developed when she worked as a consultant for MCI.

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Executive Summary

Many view the Department of Defense's (DoD) acquisition process as ripe for repair. Some of the signs illustrating this need can be found in cost overruns, late deliveries and unfulfilled expectations. In the past, the acquisition process predominantly used the Block approach or Pre-planned Product Improvement (P3I) to fulfill system requirements. Both these processes require the upfront knowledge of the end-product and any possible upgrades. Therefore, either the final capability took a long time to deliver, or the product had to be fielded before it was ready and tested. Frequently, during the long lead-times of development, production, and testing, the end-users' needs changed and/or technology improved. The change in requirements prompted alterations of strategy. These were then formulated in response to the changing face of war by Pentagon managers. The new strategies then invariably led to more upgrades or more modifications. Advancing technology also necessitated improvements. The diversity and complexity of these intermittently overhauled systems resulted in lower operational availability. One example is the current status of the Phalanx Close-in Weapon System (CIWS); this system encompasses 158 ships, 308 mounts, and 6 different baselines. The different baselines for all these mounts necessitate increases in logistics complexity. The need for appropriate spare parts and expertise adds burden to inventory management—increasing lifecycle cost and reducing operational availability. A possible solution to this problem is a new approach in Evolutionary Acquisition strategy: a process called spiral development (SD).

Spiral development is an integral part of an overall plan of Evolutionary Acquisition. Unlike P3I, spiral development is a flexible process that can be adjusted for the changing needs of warfighters and rapid innovations in technology. The evolutionary abilities are, unlike in the block approach, in incremental changes. A "spiral" is a set of acquisition activities that are incrementally incorporated into an evolving baseline. Each increment builds on the previous spiral, increases the capability of the product, and is completed at a rapid pace. This successive and

recursive set-up helps Program Managers control the risk of developing a product that may not meet user specifications. Lessons learned from the previous spiral help managers reduce the uncertainty of the outcome of the next spiral. Therefore, the flexibility of the process of spiral development allows managers to adapt system developments to meet the evolving needs of warfighters and keep pace with innovations in technology.

This research study focuses on the process, promise, and limitations of spiral acquisition/development. The researcher describes the process using a simple model. This discussion is centered on the key issues that distinguish a spiral approach from the traditional approaches implemented by the DoD. This study describes the fundamentals of the process of spiral acquisition: increments, characteristics of the increments, and the capabilities they deliver. The interest of this research is in understanding the concept of spiral acquisition as it applies specifically to Program Managers. The researcher illustrates this by a simple model incorporating successive spirals with their respective capabilities and the corresponding projects that deliver them. A fully comprehensive decision model that describes the optimal policy of whether or not to employ spiral acquisition in the public sector is beyond the scope of the current study. However, this research attempts to provide a template for that future model by expressing a set of rules that will help Program Managers articulate what it means to acquire a product or an upgrade using spiral processes. This study does not claim that spiral development is appropriate for every acquisition.

A common consequence of a spiral approach may be an increase in the diversity of parts and, hence, logistics complexity. Therefore, an extension of this research would be to explore the role of modularity in spiral acquisition. The purpose of the future component of this study is to understand if combining modular product designs will help the DoD reduce logistics complexity and lifecycle cost for systems such as CIWS and the Littoral Combatant Ship (LCS). The hypothesis is that modularity may bring rapid sequential innovations to the warfront—thereby avoiding both an obsolescence of technology and an increase in logistic complexity.

In conclusion, the analysis so far suggests two key issues, the necessity for a template or a set of rules that will aid Program Managers in understanding and implementing the concept of spiral development, and the role of modularity in spiral development. This research plans to address these issues and provide a possible road map towards a solution to them.

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I. Introduction

1.1 Background

In many observers' perspectives, the acquisition strategy of the Department of Defense is ripe for repair. Many consider the acquisition system broken. These observers note, for instance, that many acquisitions have produced huge cost overruns, late deliveries and unfulfilled expectations. The causes for these problems are numerous. Various reports written about acquisition (including a research study done by this researcher in the past regarding the Phalanx Close-in Weapon System) unveil many reasons for this seemingly unsatisfactory condition. Some such issues include: miscommunications about the final product desired, unrealistic expectations on the part of the warfighters, ever-changing budgets, occasionally inefficient production processes, and, finally, the logistic support needs created by multiple configurations. Regardless of the particular reasons, the traditional block approach used causes low operational availability and involves long lead time. Such long lead time catalyzes the fear of obsolesce of technology. All of the above are proof enough for some that the current acquisition system is inadequate. This suggests that the processes used to execute acquisition programs in the DoD need rethinking.

1.2 Literature Survey

Literature on Evolutionary Acquisition and spiral development, though not abundant, is adequate. The literature reviewed for this discussion can be divided into three groups. One is defense-related literature on spiral development; the next concerns a few applications of spiral development in the immediate past and possible future, and the third focuses on modularity in product design.

Most of the literature in the first group describes the background of and the need for Evolutionary Acquisition and explains the structure of spiral development by illustrations and technical as well as practical definitions. These articles also point out the pros and cons of spiral development. A large portion of the literature surveyed falls in the first group. For instance, Johnson and Johnson, in an overview of spiral development, describe “The Promise and Perils” of the strategy well.[1] In this text, we also learn one of the spiral success stories in regards to the Global Hawk transformation program. In another article, we learn one of the very first definition and characterization of spiral given by Boehm in 1988. Likewise, an enumeration of a set of invariant properties that the processes categorized as spiral must exhibit is well documented in a string of articles by Boehm.[2] On a different note, however, the overall technical “know how” of Evolutionary Acquisition and the comparison of spiral development with more traditional approaches are available (as explanation of the software lifecycle management methodologies) in Rendon’s texts.[3]

To clear up confusion about Evolutionary Acquisition strategies and the spiral development process, the Under Secretary of Defense issued a memorandum defining these processes in April 2002. Numerous documents quote the directive and add explanation.[4] Likewise, new acquisition policy notes provide information on what has changed and why.[5] In addition, the Army Knowledge Online Program describes how it upgraded the online portal using spiral development.[6] As per the economic aspects of spiral, the general consensus so far (from the spiral supporters) is that spiral development beats spiraling costs.[7] It is important to note, in the midst

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[1] Wayne M. Johnson, Col USAF (Ret), and Carl O. Johnson, ”The Promise and Perils of spiral development: A Practical Approach to Evolutionary Acquisition,” *Acquisition Review Quarterly* (Summer 2002): 175-189.

[2] Barry Boehm, “Spiral development: Experience, Principles, and Refinements,” ed. Wilfred J. Hansen (Special Report CMU/SEI-00-SR-08, ESC-SR-00-08. June 2000), 1–37.

[3] Rene Rendon, ”Evolutionary Acquisition,” Teaching Notes (Monterey, CA: Naval Postgraduate School, January 2005); Rene Rendon, ”Software Lifecycle Management Methodologies,” Teaching Notes (Monterey, CA: Naval Postgraduate School, January 2005).

[4] Skip Hawthorne, and Ramona Lush, ”Evolutionary Acquisition and spiral development,” *Crosstalk* (August 2002); Available from http://www.stsc.hill.af.mil/crosstalk/2002/08/easd.html; accessed 6 October 2004.

[5] ”New Acquisition Policy,” Defense Acquisition University (DoDD 5000.1, DoDI 5000.2, May 2003).

[6] Jacob Jackson, ”AKO Undergoes spiral development,” Available from www.gcn.com/cgi-bin/im.display.printable?client.id=gcndaily2&story.id=25408; accessed 6 October 2004.

[7] David F Carr, “Spiral development Beats spiraling Costs,” *Baseline* (April 2002); Available from http://www.findarticles.com/p/articles/mi_zdbln/is_200204/ai_ziff25152; Accessed 6 October 2004.

of all of the above material regarding the spiral strategy, most valuable insights included in this research regarding the innovations about spiral came from a conversation with a senior Air Force official.[8]

In addition to the theoretical definitions and descriptions of spiral, there is some documentation available regarding the implementation of the development strategy. In the discussion about the lifecycle costs of the Phalanx weapon system, the researcher noted the importance of spiral development.[9] All the literature surveyed (especially in the first group) highlights the value of spiral; but the applications are described well in Wieringa [10] and Johnson and Johnson[11]. Specifically, Wieringa describes parallels from the past in spiral development as applied to the F/A-18A strike fighter with particular attention to the aircraft's F variants. As mentioned above, spiral development as applied to the Global Hawk unmanned air system is documented with diagrams in Johnson and Johnson.

Yet, conversely, there have been several opposing views against spiral expressed in the media. The high cost of DD(X), "the ship that is sinking the Navy,"[12] or the criticism of Evolutionary Acquisition as "faith-based"[13] are just some examples. Though the critics of the Navy and spiral development feel the Navy does not have what it takes to expedite ship-building and deliver what is essential for defense, the future plans for Littoral Combat Ships (LCS)[14] support the implementation of spiral

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[8] Lorna Estep, Deputy Director, Supply Management, Air Force Material Command, interview by Aruna Apte, March 2005.

[9] Aruna Apte, "Optimizing Phalanx Weapon System Life-Cycle Support" (Acquisition Research Sponsored Report Series, Monterey, CA: Naval Postgraduate School, October 2004), 1–33.

[10] Jeffrey Wieringa, RAD. (Sel), "Spiral development and the F/A-18," *Program Manager* (May-June 2003): 50–53.

[11] Wayne M. Johnson, Col USAF (Ret), and Carl O. Johnson, "The Promise and Perils of spiral development: A Practical Approach to Evolutionary Acquisition," *Acquisition Review Quarterly* (Summer 2002): 175–189.

[12] "The Ship That's Sinking the Navy," Editorial, *The New York Times,* 23 April 2005, A12.

[13] "The Faith-Based Missile Shield," Editorial, *The New York Times*, 10 October 2004, A10.

[14] Henry C. Mustin, Vice Admiral US Navy (Ret), and Vice Admiral Douglas J. Katz, US Navy (Ret), "All Ahead Flank for LCS," *Proceedings* (The Naval Institute, February 2003). Available from http://www.military.com/Content/MoreContent1?file=NI_LCS_0203; accessed 28 March 2005.

development. These two opposing viewpoints form the second group of the literature reviewed.

The hypothesis in this paper, modularization needs to be an integral part of spiral development, was based on the research studies conducted by academia in the private sector. These studies form the third group of the literature reviewed. Krishan and Ramchandran, for example, analyze how to manage introduction of rapidly improving technology in product design. They combine product design and pricing to manage rapid sequential innovation.[15] One model in the automotive industry analyzes component-sharing when product variety exists in many industries.[16] Likewise, one research group's use of a lexicographic rule in choice inference and formulation of a linear utility function based on that result was inspiring for the model discussed in this research study.[17] In another study, Mikkola and Gassmann explain the link between modularization and open architecture.[18] This same study also describes a model used to illustrate managing innovation through modular product architecture. Interestingly, the mathematical model of analyzing the degree of modularity in a given product in architecture forms a valuable thread amongst all these articles. On another note, an article by Desai and others talks about the economic aspect of modularization.[19]

All the literature reviewed addresses certain aspects of Evolutionary Acquisition and spiral development. The researcher especially realized the

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[15] Vish Krishan, and Karthik Ramchandran, "Combining Product Design and Pricing to Manage Rapid Sequential Innovation" (Working Paper, Austin, TX: University of Texas at Austin, October 2004).

[16] Marshall Fisher, Kamalini Ramdas, and Karl Ulrich, "Component Sharing in the Management of Product Variety: A Study of Automotive Braking System," *Management Science* 45, no. 3 (March 1999): 297-315.

[17] Eli Dahan and others, "Table-Stakes: Non-compensatory Consideration-then-Choice Inference" (Working Paper, Los Angeles, CA: UCLA, February 2004).

[18] Juliana Hsuan Mikkola, and Oliver Gassman, "Managing Modularity of Product Architectures: Toward an Integrated Theory," *IEEE Transactions on Engineering Management* 50, no. 2 (May 2003): 204-218.

[19] Preyas Desai, Sundar Kekre, Suresh Radhakrishnan, and Kannan Srinivasan, "Product Differentiation and Commonality in Design: Balancing Revenue and Cost Drivers," *Management Science* 47, no. 1 (January 2001): 37-51.

importance of spiral development after analyzing the Phalanx Weapon System and its lifecycle cost. A comprehensive study that examines all aspects of the new approach was needed. The goal of this research is to understand spiral development, model it into a template to be used by Program Managers and try to answer some of the questions raised by the Acquisition Research community.

1.3 Motivation

In the past, DoD Acquisition strategies predominantly used the Block approach or Pre-planned Product Improvement, P3I. Both the processes require the upfront knowledge of the end product or the potential upgrades. Therefore, either the time until delivery of final capability was too long, or the fielding of the product was premature. Frequently, during the long lead times of development, production, and testing, the needs of the users changed. The change in requirements prompted alterations of strategy. These were then formulated in response to the changing face of war by Pentagon managers. The new strategies then invariably led to more upgrades or more modifications. The diversity and complexity of these intermittently overhauled systems resulted in lower operational availability (Ao). For example, at present there exists a weapon system with 158 ships, 308 mounts, and 6 different baselines. The different baselines for all these mounts necessitate an increase in the complexity of logistics. The need for appropriate spare parts and expertise adds burden to the inventory management, increasing the lifecycle cost and reducing the operational availability of the system. All these reasons lead to partial or full-blown failures. Under such circumstances, the experts from the DoD (as well as from non-DoD sources) attempt to fix the system. One such possible solution to this problem is perceived to be the new directive for acquisition: a process called spiral development, an evolutionary approach for acquisition classified as one method of Evolutionary Acquisition.

1.4 Focus of the Research

In this research, the researcher studies spiral development. Some of the questions raised and answered are: What is the difference between spiral and

Evolutionary Development? How is spiral different from the Block approach and P3I? When should spiral development be implemented? Is this the magic tool from the acquisition toolbox that will cure all that is ailing the Acquisition system? How will spiral development affect project management and Program Managers? This research study focuses on the process, promise, and limitations of spiral development. It is centered on the key issues that distinguish the spiral approach from the traditional approaches implemented by the DoD so far.

1.5 Scope, Methodology, and Limitations

This research studies the fundamentals of the process of spiral development by analyzing the spiral increments of this acquisition method, characteristics of the increments, and the capabilities they deliver. The interest in this research is in understanding the concept of spiral development as it applies, specifically, to Program Managers (PM). The researcher illustrates this by creating a simple model incorporating successive spirals with their respective capabilities and the corresponding projects that deliver them. A fully comprehensive decision model that describes the optimal policy of whether or not to employ spiral development in the public sector is beyond the scope of the current study. However, this research attempts to provide a template by expressing a set of rules that will help the PM articulate what it means to acquire a product or an upgrade using the spiral process. This study does not claim that spiral development is appropriate for every acquisition.

This research, just like the topic it studies, is a work in progress. Analysis so far suggests two key issues: the necessity of a template or a set of rules to standardize the eluding concept of spiral development that will aid Program Managers and the necessity for those Program Managers to understand the role of modularity in spiral development. This research plans to address these issues and provide a possible road map to navigate through them. In order to achieve this goal, this paper will look at lessons learned by private-sector industries and private-sector practices that could be applicable in the public sector. It will also identify issues that need further study. For example, a common consequence of spiral development may be an increase in diversity of parts and, hence, logistics complexity. Therefore, an extension of this research explores the role of modularity in spiral development. Economies of scale are an important benefit of modularity. The interest in the latter part of this study is to understand if combining modular product design will help the DoD reduce logistics complexity and lifecycle cost for systems such as CIWS and LCS. The hypothesis is that modularity may bring rapid sequential innovations to the war front, thereby avoiding obsolescence of technology, decreasing logistic complexity and reducing cost due to economies of scale.

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II. Spiral: A Perspective

2.1 Spiral, Block, and P3I Approach

Two forms of Evolutionary Acquisition Strategy that can be implemented are the traditional Incremental Development and spiral development. Both strategies are incremental approaches. Incremental Development approaches used in the past, such as the Block approach, had larger increments than the increments used in the current approach of spiral development. The traditional approach may have several pieces of an integrated system that must be fielded at the same time. In Block Development (one example of an Incremental Approach), a desired capability is identified, and the end-state is known. This requirement is met over time by a contractor developing several increments. These increments are subject to the availability of mature technology. However, in spiral development, a desired capability is identified, but the end-state requirements are not known at program initiation. Requirements are refined through demonstration and risk management. There is continuous user feedback, and each increment in spiral development (SD) provides the user the best possible capability.

Every Incremental Development process results in a militarily useful and supportable operational capability that can be developed, produced or acquired, deployed and sustained. A traditional Block approach involves fielding a revamped, upgraded capability. These developments may require a long lead time, and the desired end-state of the entire development is usually agreed upon. A Pre-planned Product (P3I) Improvement approach is an approach where the developer knows upfront what the entire development will look like. P3I provides for adding improved capability to a mature system. Thus, both the Block and P3I approaches establish a core capability with additional increments of functionality added over time where the functionality of all blocks is defined upfront. Here the increments can be substantial in length of time and capability whereas in SD, these increments are much smaller. The traditional Incremental Development assumes the knowledge of end capability and may be a new product from or improvement of an old system. SD does not require complete knowledge of the end capability but understanding of such is sufficient. During the Cold-War era, the warfighter's environment was better known—hence, strategies used were well established. The defense system was comparatively stable. In the current war against terror, the face of war and the mechanisms necessary to fight it effectively are ever-changing. While the Block or P3I approach works in the stable system, spiral development, this researcher believes, is the solution for dynamic systems.

The process of spiral development is part of the overall plan of moving towards Evolutionary Acquisition. Unlike P3I, spiral development is a flexible process that can be adjusted for the changing needs of the warfighters and rapid innovations in technology. What is evolutionary about it is that, unlike in the Block approach, there are small incremental changes in spiral acquisition. Table 1 lists some of the differences between the Block approach and the spiral approach.

Table 1. Differences between the Block and Spiral Approaches

Spiral	Block
1. May involve developments that do not support the end goal Begin in previous spiral but actual improvements in next spiral	1. Upfront knowledge of all upgrades
2. Involves Rapid Increments	2. May take longer but get the final capability to user
3. Have idea about the end product	3. Usually have full knowledge of the end product
4. In implementation, may have to bring aircraft or ship to depot more than once	4. Once fielded, does not usually have to return to depot
5. Increments are short and flexible	5. Increments are not flexible

2.2 What is Spiral?

Spiral development is a set of acquisition activities that are incorporated in an evolving baseline using increments. Each increment increases the capability of the product. Each increment is completed at a rapid pace. Each increment builds over each previous spiral. This successive and recursive set-up helps Program Managers manage the risk of developing a product that may not meet the user specifications. Lessons learned from the previous spiral help reduce the uncertainty of the outcome of the next spiral. The flexibility of the process of spiral development is one of the keystones of this approach. Flexibility is essential to meet the evolving needs of the warfighters and to exploit innovations in technology. Spiral development is an organized project plan intended to eliminate major risks as early in the game as possible. Therefore, each increment includes a reassessment of risks and assumptions. Each increment also creates a functioning prototype, at the end of which lessons learned are evaluated. Before starting the next increment, a decision is made about whether to proceed or not.

The publication of the latest revisions of DoD directives 5000.1 and 5000.2 established a preference for the use of Evolutionary Acquisition Strategies relying on a spiral development process. Evolutionary Acquisition, therefore, is a strategy or an approach to acquisition; spiral development is one of the processes that implement this strategy. It is believed that evolutionary methods will provide the best means of getting advance technologies to the warfighter quickly while continually improving particular systems' capabilities. Evolutionary Acquisition, the strategy, and spiral development, the process, are focused on providing the warfighter with an initial capability (that may not be the final capability) as a tradeoff for earlier delivery, flexibility, affordability, and risk reduction. The capabilities delivered are provided over a shorter period of time—followed by subsequent increments of capability over time—that incorporate the latest technology and flexibility to reach the full capability of the system. Each increment delivers capability that meets the threshold set by the user for that increment. However, the first increment may deliver only 60-80% of the desired final capability.

Spiral, as defined earlier, is part of an overall plan to alter the acquisition process. The AF Instruction 63-123 for Command and Control Systems in the Air Force states, "the spiral development process is an iterative set of sub-processes that may include: establishing performance objectives; design; code, fabricate, and integrate; experiment; test; assess operational utility; make tradeoffs; and deliver."[20]

2.3 Model for Spiral

Based on the various definitions of spiral development, the process can now be formalized in a mathematical model. To describe the model, an introduction to the notation is necessary.

Notation:

Set of spirals: $S_1, S_2, \ldots, S_n$

Set of capabilities: $k_1, k_2, \ldots,$

Weights for capabilities corresponding to each spiral:

$\pi_1, \pi_2, \ldots, \pi_n$ where $0 \leq \pi_t < 1$ for $t = 1, 2, \ldots, n$

Final (or end) capability: $K = \sum_{t=1}^{n} k_t$

Capability of spiral $S_1 = f(S_1) = k_1 = \pi_1 K$

Capability of spiral $S_2 = f(S_2) = f(S_1) + k_2 = \pi_1 K + \pi_2 K = K \sum_{t=1}^{2} \pi_t$

Capability of spiral $S_3 = f(S_3) = f(S_2) + k_3 = K \sum_{t=1}^{2} \pi_t + \pi_3 K = K \sum_{t=1}^{3} \pi_t$

$\vdots \qquad \vdots \quad \vdots \quad \vdots \quad \vdots \qquad \vdots$

[20] Air Force. *The AF Instruction 63-123 for Command and Control Systems in the Air Force*.

$$\vdots \qquad \vdots \quad \vdots \quad \vdots \quad \vdots \qquad \vdots$$

Capability of spiral $S_{n-1} = f(S_{n-1}) = f(S_{n-2}) + k_{n-1} = K\sum_{t=1}^{n-2}\pi_t + \pi_{n-1}K = K\sum_{t=1}^{n-1}\pi_t$

Capability of spiral $S_n = f(S_n) = f(S_{n-1}) + k_n = K\sum_{t=1}^{n-1}\pi_t + \pi_n K = K\sum_{t=1}^{n}\pi_t$

Capability k_t ($0< k_t<1$) is a function of spiral S_t. k_t is a weighted capability of the final capability K where the weight π_t is $0 \le \pi_t < 1$. Since spiral development is an incremental approach, a set of spirals (which contains n spirals) is defined as S. Based on the essence of spiral development; the researcher believes $n \geq 3$. Each spiral is a cumulative spiral in terms of its capability; this means the t^{th} spiral has capability of spirals S_1 through S_{t-1}. This aspect of the definition creates the dependency and, therefore, succession between spirals. Spiral S_t cannot be released until S_{t-1} is completed. Thus, risks encountered during the execution of a current spiral can be examined and dealt with in future spirals. The properties of this model are as follows:

Property 1: Successive spirals deliver increasing capabilities (i.e., capability of current spiral is greater than the capability of previous spiral).

Explanation: By definition,

$f(S_t) = f(S_{t-1}) + k_t$ for $t = 2, .. n$

since $k_t > 0$, $f(S_t) > f(S_{t-1})$

This property of the model maintains the increasing capabilities of all the spirals. It also illustrates that spirals are dependent on previous spirals in terms of their capabilities. Therefore, lessons learned from previous spirals can be passed on to the next spiral.

In spiral developments, the end capability may not be known. And, therefore, delivery of the end capability is an abstract concept. However, DoD Program

Managers have to deal in the real world. Therefore, we propose the following property.

Property 2: If capabilities corresponding to each spiral add up to the final capability, then the sum of all the weights is 1. **(**i.e., if $K = \sum_{t=1}^{n} k_t$ then $\sum_{t=1}^{n} \pi_t = 1$).

Explanation: $f(S_1) = k_1 = \pi_1 K$

$$f(S_2) = k_1 + k_2 = \pi_1 K + \pi_2 K = K \sum_{t=1}^{2} \pi_t$$

$$f(S_t) = k_1 + k_2 + \ldots + k_t = \pi_1 K + \pi_2 K + \ldots + \pi_t K = K \sum_{i=1}^{t} \pi_i$$

$$f(S_n) = k_1 + k_2 + \ldots + k_n = \pi_1 K + \pi_2 K + \ldots + \pi_n K = K \sum_{i=1}^{n} \pi_i$$

Since the last spiral delivers the final and, therefore, the total capability,

$K \sum_{i=1}^{n} \pi_i = K$ implies that $\sum_{i=1}^{n} \pi_i = 1$

It should be noted that due to the synergy of the spirals, for Property 2 the sum may be greater than one. However, the result describes the flexibility of the spiral development. Choice of the weights π_1, π_2,…., π_n provide the flexibility. $\sum_{i=1}^{n} \pi_i = 1$ provides structure (instead of an abstract capability) to both the warfighter and the Program Manager and assumes the delivery of the entire product. The actual values of π_t are up to the discretion of the user and the Program Manager. Based on the literature about Evolutionary Acquisition and spiral development, researchers believe implicitly that the first spiral delivers 60-80% of the final capability. Therefore, this text proposes that π_1 be greater than *0.5.* This researcher recommends that each π_t have Property 3.

Property 3: Weights of each π_t forms a decreasing sequence given by $\pi_1 \geq \pi_2 \geq \ldots \geq \pi_n$.

Property 3 is recommended but not required. The order of each π_t will help the warfighter. Since all the weights have to add up to *1*, capabilities are front-loaded. Larger capabilities are delivered first; then, they decrease in their capacity. However, the model ensures that delivered capabilities are in increasing order and occur at the same time the fraction of the remaining capability decreases. In terms of weights, this relationship means that $\frac{\pi_t}{\pi_{t-1}} \leq 1$.

This is a model based on the researcher's perspective of spiral development. It proposes a template of spirals $\{S_1, S_2, \ldots, S_n\}$ and their corresponding capabilities $\{k_1, k_2, \ldots, k_n\}$ that are weighted $\{\pi_1, \pi_2, \ldots, \pi_n\}$ of the final capability *K.* This structure, along with its properties, can help Program Managers define spiral development as it applies to their programs. The model maintains the "spirit" of spiral development by requiring that each successive spiral should deliver more capability than the previous spiral. Choice of weights in the model allows flexibility, and the structure assures the delivery of final capability by requiring that all the capabilities of individual spirals add up to the final capability. The recommendation of the added characteristic of each π_t provides a map for possible values of the weights.

It is necessary to note that the model does not present one aspect of the spiral—risk evaluation. The researcher believes that incorporating risk (using stochasticity) is an integral part of spiral; that incorporation will occur as spiral is implemented and data about probabilities becomes available. In the future, the researcher plans to expand the above model to describe spiral development as a set of threshold values that will provide guidance for Program Managers. It is also important to note that, this model being a high-level design of SD, all the intricacies and nuances have not been incorporated.

2.4 Limitations of Spiral

2.4.1 Lack of Understanding

Spiral development, though a sound concept, has already acquired a reputation as “a mysterious process” in acquisition. Practitioners who defined it and have analyzed it understand it well. However, the definition itself (due to its flexible nature and deviation from traditional approaches) is not very clear. Hence, there exist various versions and perceptions of it. Implementation—or even the intent of implementation—has invoked responses from critics such as this *New York Times* editorial:

> The Faith-Based Missile Shield: This wisp of the old Star Wars fever dream is bedeviled by missing components and unproven premises. The Pentagon has suspended normal accountability standards in favor of what military proponents euphemistically term “evolutionary acquisition.” This means spend and build now, and attempt credible tests when and if all parts finally arrive.[21]

Another editorial from the *Times* suggests that spiral development, which incorporates the latest technology due to its incremental process, satisfies the Navy’s hunger for impressive technology whether it is needed or not.[22] Spiral development will be better understood the more it is discussed. As more studies focus on this new concept and as it is implemented, the ”promises and perils” of spiral will be clarified. The perceptions of Program Managers seem to be that it is the same old strategy but repackaged. This comment touches on the most important aspect of the limitations of spiral. It doesn’t matter how good the process is—if it is not user-friendly, it will not be implemented. In order to make spiral user-friendly, it is essential that spiral is well understood.

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[21] ”The Faith-Based Missile Shield,” Editorial, *The New York Times*, 10 October 2004, A10.

[22] ”The Ship That’s Sinking the Navy,” Editorial, *The New York Times,* 23 April 2005, A12.

2.4.2 Challenges in Implementation

Success for spiral development implementation lies in the critical aspect of definition of requirements. The vital goal of providing rapidly developed smaller projects that are quickly fielded to the warfighter will only be achieved if clearly defined requirement statements are established ahead of time. The key requirement issues are identified in the following paragraphs. These issues are the challenges spiral development must address in order for the process to be deemed a success.

The first requirement is that the successive rapid developments have to be independent of each other. This is a prerequisite for risk reduction. Though the projects that deliver these capabilities must be synergistic with the user, they also must satisfy separate criteria so Program Managers can allocate and evaluate risks across all aspects of the program. This independence is the key to controlling risks.

The second requirement spiral development must address is that the user must be involved in the evolving baseline of the subsequent increments. The user's contribution has two aspects. One is that the user should be an active participant in planning, controlling, and producing the program. The other is that the warfighter and Program Manager must trust each other. The knowledgeable persons in this area,[23] those who have been in the thick of it, recognize that user feedback is crucial and a major prerequisite for the successful implementation of spiral development.

Another pressure asserting itself on implementation is that the user community has to understand and agree with this concept of incremental capability. It is critical that the user be educated in terms of the evolutionary concept of spiral and its incremental introduction of capabilities. The user also must understand the concept of earlier fielding of systems without the final capability. The user, then, must state upfront a willingness to initially field less-than-perfect systems. The user must understand that the first installment of capabilities will not be the final product, but will be a sizeable portion of it. Each warfighter has to believe that the Program

[23] Lorna Estep, Deputy Director, Supply Management, Air Force Material Command, interview by Aruna Apte, March 2005.

Managers will deliver what has been agreed upon. Here “agreed upon” are the key words. Users must not compare the capability of the first spiral with the potential of the system it is expected to deliver. The main issue, then, is controlling user anticipation. A spiral approach will not work if the user cannot accept less than 100% of the final capability at the start. The group led by the user must agree on content of the spiral increments; then, it must structure the process so that the Evolutionary Acquisition Strategy can be supported by documents.

The desired method of communication is analogous to a wheel with the Program Manager (PM) at the hub. All transfer of information is routed through the PM. Each stakeholder communicates his/her needs to the PM. The PM, being at the center of this network, manages performance, schedule and costs. Ideally, the PM should exercise leadership over teams formed for the execution of the project. Necessary interaction should not be restricted to warfighters and Program Managers. Communication between the warfighter, the program office in charge of managing the product, Pentagon staff supporting the program, and the contractor that ultimately builds the system is essential. Though routing communications through the PM on every occasion provides the PM with essential information for successful completion of the project and protects the project from escalating costs, increase in non-direct communication leads to longer cycle times. Delay in interaction increases the time pressure on the vendor for delivery of the spiral. This stress may lead to the vendor’s cutting corners in the quality of the product which may result in failure of process. Therefore, this author believes that though unusual and perhaps risky for cost control, the process of communication within this group of principal players is essential and needs to be time critical. The use of Integrated Product Teams is, therefore, a natural suggested response to this challenge. It is necessary that there be formal, regularly scheduled meetings amongst all these players at the beginning of each spiral increment so that all parties involved agree upon the content, duration and requirements of the process ahead of time. As the program evolves, the requirement, content and, therefore, duration may change. Flexibility (which is the prominent aspect of spiral development) will allow these changes. But, with flexibility and freedom comes responsibility and accountability.

Therefore, the group members must function as a team—they must communicate with and trust the other team-members; otherwise, the success of the spiral will be jeopardized.

2.4.3 Logistic Complexity

Spiral, due to its incremental nature, is also a logistical challenge. The fielded systems that are at different stages in the program will yield more than one configuration of the system. Multiple configurations are a logistic nightmare that leads to low operational availability. These instances already exist without the introduction of spiral. There are, currently, various causes for it. For instance, diminishing availability of manufacturing sources forces custom production—leading to escalating costs. If there are many such instances, production and distribution is a challenge. Technological improvements also lead to logistic delay. The Block approaches and P3I efforts are the usual suspects for the increase in the mean logistic delay time (MLDT); this increase, in turn, reduces the operational availability of the system.

The reliability literature[24] and the Military Handbook for Operational Reliability[25] define A_o, operational availability, as the quotient of "up time" over "total time." This equation is the performance measurement of a system.

Equation 1. Performance Measurement of a System

$$A_o = \frac{MTBF}{MTBF + MTTR + MLDT}$$

MTBF is the mean time between failures. MTTR is mean time to repair, which can be further explained as "time it takes to remove interference, remove, replace, and test the failed component, return the equipment to its original condition, and

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[24] Benjamin S. Blanchard, *Logistics Engineering and Management*, 6th ed. (Upper Saddle River, NJ: Prentice Hall, 2004.

[25] OPNAVINST, *Operational Availability Handbook: A Practical Guide for Military System, Subsystem and Equipment*. (300.12A).

replace and retest any system interference removed to get to the failed equipment."[26] MLDT, or mean logistic delay time, is the cumulative time required by all logistics processes to support the requisite repair.

MTBF appears in the numerator as well as in the denominator. So, changes in MTBF do not affect A_o necessarily. Equation 1 also includes MTTR in the denominator. This variable is normally a small number, so it does not influence A_o as much as other factors. This leaves mean logistic delay time (MLDT) as the mathematical driver of Equation 1. MLDT includes Mean Supply Response Time (MSRT), Mean Administrative Delay Time (MADT) and Mean Outside Assistance Delay Time (MOADT). MSRT (due to transportation, especially if there exists a high percentage of absent spare parts in the inventory or parts not easily accessible) and MOADT (due to lack of expertise of the users) usually have larger values. Therefore, to improve A_o, MSRT and MOADT (and, consequently, MLDT) should be improved. Multiple configurations lead to logistic complexity; this, in turn, increases all the factors associated with logistics. Equation 1 illustrates that this leads to lower operational availability.

The Block approach and P3 I both tend to follow the pattern described above. But the difference between these approaches and spiral is that spiral development *expects* different configurations. Therefore, spiral plans for them and manages them. Its flexibility and increments allow the capability to be fielded earlier without the expectation of a "finished" product; it also allows flexibility in the production and distribution. Logistic complexity, though an effect of spiral, can be dealt with by the very structure of spiral. This researcher also believes the management of logistics can be further facilitated by introducing modularization.

[26] Benjamin S. Blanchard, *Logistics Engineering and Management*, 6th ed. (Upper Saddle River, NJ: Prentice Hall, 2004.

III. Modularity in Spiral

The increase in logistic complexity due to the incremental structure of spiral development is one inadequacy that can be addressed by introducing modularization in capabilities. Products whose performance can be improved by replacing a minimal set of components are termed “modular upgradeable.” A spiral development approach enables the introduction of incremental capabilities delivered at a fast pace via a modular approach. Thus, sustenance of the resulting multiple configurations places demands on supporting the logistic systems. Various parts/products will be needed at different times. Normally, diversity of parts leads to high costs and costly logistics. These costs, however, can be mitigated by an adequately planned modular approach.

It is important to note that spiral development, with its inherent characteristic of increments and flexibility, can manage logistic complexity better than the Block approach. It allows projection and forecast of needed parts/modules as each spiral is launched. Modularization has similar properties, increments and flexibility. Therefore, modularization may allow better management of production and distribution and, thereby, encourage reduction in logistic complexity. So, whether spiral development is used for launching a new product or to improve an existing product, adding modularization to the process creates potential to reduce logistic complexity. However, it should be noted that with so many unique products and projects across Defense acquisition programs, modularization across the system may not be feasible.

An advantage of modularization in the private sector is in managing rapid, sequential innovation and economies of scale. This concept of combining product design to incorporate ever-improving technology may be imported to the DoD via spiral development with some modification. The interest in this research is in understanding if combining product design with logistics complexity and cost can help the DoD navigate the trajectory of rapid product improvement—satisfying warfighter needs and minimizing cost without constraining the Department’s degrees of freedom. Product design under existing DoD directives regarding spiral development has degrees of freedom, such as new features, new strategy, and new defense initiatives. In the private sector, there exist several different strategies by which the product can be made ”modular upgradeable" with different implications.

In the private sector, Proprietary Modular Upgradeable (PMU) systems are systems in which customers must purchase both the improving and stable modules from the same firm. Such a firm is said to follow a PMU approach. For example, in cell phones, by making subsystems such as camera, battery, and storage upgradeable in modules, a firm can potentially address customer concerns about obsolesce. When the product is designed so the stable module is a commodity that can be purchased from the open market, the firm is said to follow a non-proprietary modular upgradeable (NPMU) approach. For example, personal computers are used for several generations of microprocessors with the same combination of industry-standard non-proprietary peripherals. In other words, Microsoft products work with a variety of microprocessors. This author believes both the models for modular upgradeability could be applicable with spiral development.

Combining modularization with spiral development has the following advantages. Most importantly, the combination will reduce logistic complexity. In the private sector, modularization has achieved great results. By tailoring it to the DoD’s needs, similar results could be achieved. One of the advantages of the method in the private sector is that customers find it easier to make their purchase decisions when their initial investment is not completely lost by subsequent introduction of superior products. In the DoD, the acquisition programs represent the customer. Here, commitment to localizing performance improvements and modular development is more effective than integral architecture. In other words, amongst defense initiatives, open architecture is a “good thing.” Modular designs are more conducive to a faster launch; therefore, from a warfighter’s view, modularity would definitely be a great advantage. Likewise, using standard components, a NPMU approach might be an attractive option when cost-side advantages are factored in. With logistics costs skyrocketing and the DoD beginning to run ships as private enterprises, this aspect of modularization is worth investigating. However, it should be noted that incentives for modularization and maintenance of proprietary control are dependent on the warfighters' adoption of spiral development. It should also be noted that when direct or opportunity cost of modularization using the propriety approach is high, non-proprietary (or integral architecture) may be preferable.

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IV. Examples of Spiral

4.1 Past: Phalanx

One situation from the past in which spiral development could have been of great benefit was Phalanx.[27] The Phalanx Close-in Weapon System (CIWS) was built as a terminal defense against current and evolving anti-ship missiles and aircraft which penetrate outer fleet defensive envelopes. CIWS has evolved substantially since initial deployment. Since 1980, the original Block 0 has been improved multiple times. Changes include: Block 1 Baseline/L0 in 1988, Block 1 Baseline/L1 in 1991, Block 1 Baseline/L2 in 1992, Block 1A in 1996, and Block 1B in 1999.[28] The CIWS overhaul program then began to accept Block 0 mounts and replace them with improved Block 1 systems. Prior to this, in the early nineties, the Naval Ordnance Station/Louisville (NOSL) began to perform a thorough Class A overhaul. Such an overhaul included a complete teardown, stripping, resurfacing, painting, and individual testing of the mounts. The reliability of the post-overhaul systems was as good as the benchmark of the Block 0 production systems and was greatly improved in comparison to the older systems. CIWS was upgraded as the requirements for such a weapon system evolved to meet emerging threats.

Due to the Base Realignment and Closure (BRAC) process, in 1995, the NOSL depot was scheduled for closure. Instead, it was purchased by the state of Kentucky and leased to the primary contractor for the CIWS overhaul program. The costs for overhauls escalated, while sponsor funding for the program became erratic. The funding issues and the soaring costs forced the Class A overhauls to be replaced by Class B overhauls. Class B overhauls were substantially reduced in

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[27] Aruna Apte, “Optimizing Phalanx Weapon System Life-Cycle Support” (Acquisition Research Sponsored Report Series Monterey, CA: Naval Postgraduate School, October 2004), 1–33.

[28] PEOIWS, *Phalanx Reliability Maintainability & Availability (RM&A) Handbook*, 6th Revision. (March 2004).

scope compared to Class A overhauls. They were also not preset procedures, but were flexible to the observed condition of the mounts.

The class B overhaul effort that started in 1999, and was in fleet use for three years, did not meet expectations in service reliability or cost. During the period of 1998–2002, overall maintenance cost increased 53%. From FY02 actual expense to the projected FY03 expenses, costs increased 28%. However, funding during these years did not conform to the needs of the system. Instead, the numbers were erratic: $47.26M in 1999, $21.76M in 2000, $46.17M in 2001.

Obviously, a complex, mature, large, and diverse weapon system like CIWS has numerous interdependencies which are, by their very nature, difficult to analyze. The large population of the system magnifies the small increase in cost to large proportions across the system, and the diversity of the system (due to different baselines) creates unique logistic challenges. This, in turn, creates unique problems. Currently, CIWS has 158 ships, 308 mounts, and 6 baselines. The different baselines for all these mounts necessitate increased logistical complexity to provide necessary spares; this complexity, likewise, increases the lack of available maintenance expertise on the ship and places a heavy burden on inventory managers to carry the required spare parts.

The diversification of CIWS baselines, which occurred over time, contributed to the high cost of maintenance. More baselines simply increase complexity. Several types of mounts need a wider variety of parts and people with different ship-board expertise. Logistics for a line of products that have a large variance is a complex state of affairs. Maintaining the inventory of and expertise for parts with diversity costs more. Some of this expansion is deliberate; yet, in some cases it is forced due to evolving security issues or strategy or both. In the case of CIWS, diversification occurred because of the system's unique place in the weapon system and rapidly-changing defense needs. But there is a lesson to be learned here: diverse baselines have high variable costs.

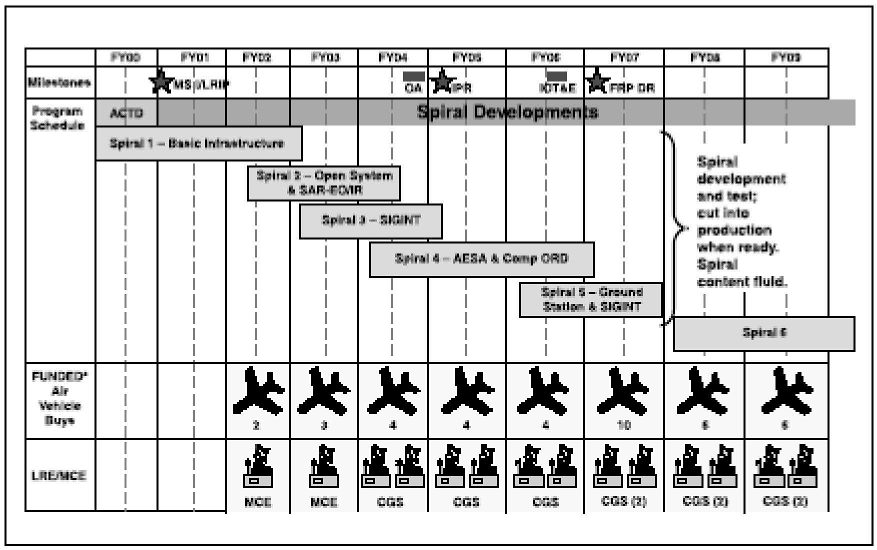
On the other hand, existence of only one baseline invokes the economies of scale and brings costs down. A great example in the private-sector transportation industry is that of American Airlines and Southwest Airlines. American has 13 types of airplanes which increase the diversity of parts needed and, therefore, logistic complexity. Yet, Southwest has only one type of plane—increasing the efficiency of the company's operations and making it economically successful. But, the defense industry does not have the luxury of single product lines; therefore, the DoD should examine spiral development, which can work economically without compromising operational availability. There is benefit in starting small and expanding in scope and scale gradually. Then, the process of spiral development—introducing a prototype or a small number of products and then gradually expanding the original product or enhancement through the fleet—would have the operational advantage of propagating the product line in two dimensions, scale and scope. Fixed cost will be generally low. Variable costs could be controlled by managing the increments of spiral development.

4.2 Present: Global Hawk

In the winter of 2001, the Global Hawk unmanned air system (which started as an Advanced Concept Technology Demonstration (ACTD) program) entered Engineering and Manufacturing Development (EMD). The warfighter wanted something different than what ACTD had fielded. This two-staged development would have taken seven years and two configurations before the final capability desired by the warfighter was completed. Though the initial capability was basic, there were challenges in fielding the subsequent capabilities.

Initially, this task was programmed as two spirals of length three and four years which, for all practical purposes, turned out to be Blocks. However, in the summer of 2001, the Global Hawk became a spiral development program. As explained in Figure 1, the added capabilities needed by the warfighter were programmed for production on a yearly basis. The user proposed the requirements up front, but agreed on flexible results to keep up with the changing environment. Thus, the incremental capabilities were flexible—spirals in a true sense. There was better communication between the parties concerned; therefore, the risk factor was reduced. Between the rapid sequential deliveries of the spirals, the warfighter was allowed to add or remove the upcoming requirements. For each spiral, review and risk analysis were performed to ensure that the program was on track.

Figure 1. Draft Example of a Global Hawk Spiral Development



Source: Jeffrey Wieringa, Rear Adm. (Sel), “Spiral development and the F/A-18,” Program Manager May-June 2003 50 - 53

4.3 Future: Littoral Combat Ship

Torpedo-firing submarines, an array of new and old mines, swarming small, fast, missile-firing boats—all form a real, relatively cheap, formidable, rapidly growing and collective global threat to the US Navy. Part of the Navy’s answer to these threats is in two recently introduced bold and new concepts: the family of Littoral Combat Ships (LCS) and a shipbuilding concept that will deliver ships faster and with designs adaptable to new technology. The critics of these concepts claim that LCS will not function as planned; the system is too small; costs will be very high, and technologies are not mature enough to justify the effort. Yet, there is more at stake here than just the characteristics of LCS. The Navy needs to regain control of its shipbuilding program. In the past, shipbuilding budgets have been unstable, unrealistic, and unpredictable. The traditional way the Navy designs and builds ships is deliberate, risk-intolerant and challenging for future upgrades. This conservative approach inhibits rapid insertion of new technology essential in critical mission areas. Adding upgrades later through major overhaul/upgrade programs based on past records tend to be very costly—particularly when viewed from the perspective of remaining hull life.

The process of spiral development, if applied to certain aspects of LCS's design and acquisition, will help the Navy build ships faster and in increments—first delivering a basic capability, and, subsequently, including improvements based on testing and advanced technology. It is said that the LCS in this century is what the aircraft carrier was to the Navy in the last century. Spiral development offers the Navy a potential alternative to correct costly shipbuilding paradigms.

The spiral development approach has much potential for containing traditional shipbuilding costs. LCS, brought to the Fleet via spiral development, could be a catalyst in enabling rapid, sequential innovation applied to more ships at sea at a faster rate. Current DoD initiatives that encourage "rewriting the rules as you go" offer the Navy this opportunity. LCS is a sound concept that is innovative, cost effective, and introduces capabilities as needed. But, more importantly, it provides the Evolutionary Acquisition model necessary for the Navy to bring ship-building in line with modern business practices. It also aggressively addresses one major issue for many surface-combatant modernization plans—bringing modern technologies into the fleet at the least expense.

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V. Conclusions and Recommendations

This research has studied the process of spiral development as one part of Evolutionary Acquisition and has offered a perspective on that approach. It has provided the definition of spiral development, motivation behind it and a survey of various articles written about it. In addition, it has described the process of spiral development by comparing it with the traditional Block approach. It analyzed the process of spiral development by formulating a mathematical model that will serve as a template for Program Managers. This is one of the researcher's major contributions to the current studies of spiral development. A research study validating this model will be of great benefit to Acquisition Research. The researcher is currently working on the outline of such a study. In this study, interviews with Program Managers who could have used spiral, who may be in the process of implementing it, or are planning to do so in the near future will be reviewed.

This discussion has also listed the challenges of spiral development, such as: lack of insight on the process itself, the requirements necessary for the success of spiral, and, most importantly, logistic complexity instigated by spiral. The first will diminish as more literature about spiral is produced and becomes available. As more programs use spiral development, the acquisition community will become better acquainted with the fundamentals of the process. The same can be said about requirements of spiral; more exposure will teach both warfighters and Program Mangers to articulate and communicate each system's requirements. Logistic complexity can be somewhat reduced using modularization. Yet, this hypothesis needs further testing, and more research in that area needs to be conducted.

The notion of introducing modularization in spiral development is also an important contribution of this research. Modularization is a concept and practice frequently used in the private sector that is worth investigating for possible adoption into the evolving process of spiral development. In the immediate future, this researcher plans to extend the basic model of spiral development by further incorporating modularization.

The implementation of spiral (past, present, and future) has been mentioned in this article. The success story of Global Hawk has been described. Yet, a case study or a research project that chronicles a step-by-step implementation of spiral would be valuable. The scope of this research project did not include the cost factor of the spiral process, but this aspect of spiral must be addressed in the near future; the researcher has planned a case study to that effect.

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